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Isolated Pico-Hydropower Generation for Power Quality Improvement Using 24 Pulse Ac-Dc Converter

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ABSTRACT

A comparative study between the topologies consisting of the Conventional Electronic Load Controller and the Proposed Electronic Load controller (ELC)has been carried out in this paper for the power Quality Improvement in a conventional Electronic Load controller used for Isolated pico-hydropower generation using Asynchronous generator (AG). A polygon wound autotransformer with reduced Kilo Volts ampere rating is employed in the proposed ELC for reducing the harmonic current reduction in order to meet the power quality requirements as prescribed by IEEE standard. The conventional ELC employs six-pulse-bridge-rectifier and the Proposed ELC employs twenty four -pulse-bridge-rectifier. The simulation of conventional Electronic Load Controller (ELC) and proposed load controller is carried out in MATLAB/SIMULINK with simpower systems tool box.

Keywords:- Electronic load controller (ELC), isolated asynchronous generator (IAG), pico-hydroturbine, and polygon wound autotransformer.

I. INTRODUCTION

The 6-pulse diode-bridge rectifier suffers from operating problems [1-2], such as poor power factor “PF”, injection of harmonic currents into the ac mains, equipment overheating due to harmonic-current absorption, input ac mains voltage distortion, and malfunction of sensitive electronic equipment due to electromagnetic interference. In order to prevent the harmonics from negatively affecting the utility lines, an IEEE Standard 519 and IEC 555-3 [3] has been established to give limits on voltage and current distortions. This has led to the consistent research in innovation of various configurations of ac–dc converters for mitigating these harmonics and to comply with these standards.

Several methods based on the principle of increasing the number of pulses in ac-dc converters have been presented which are simple to implement [4-7]. These methods use two or more converters, where the harmonics generated by one converter are cancelled by the other converter, by a proper phase shift. To reduce the transformer rating, multi-pulse converters have been reported in the literature [7]. Increasing the number of pulses further results in improvement in various power-quality indexes but along with the additional cost of different converters and increased system complexity. This paper presents a novel reduced-rating transformer based 24-pulse ac-dc converter applying the same existing 6-pulse converter with addition of pulse multiplication unit to improve power quality The pulse multiplication unit is achieved by multi-step reactor instead of the conventional inter phase transformer with three controlled switches. Mathematical analysis and simulation using MATLAB software is presented for twelve and 24-pulse converters. A comparison between the two converters “from power quality indices point of view” is held to monitor how much power quality indices are improved with the increase of number of pulses. These simulation results are verified by experimental results using the 36-pulse converter with the pulse multiplication technique using a 1 KW proto-type model. A comparison between conventional 6-pulse and 24-pulse converter is concluded referred to the different power quality indices to comply with the IEEE 519 and IEC 555-3.

II. SYSTEM DESCRIPTION AND ANALYSIS

Fig. 1 shows the isolated picohydro generating system that consists of an IAG, excitation capacitor, consumer loads, within the prescribed limits by IEEE standards [8] as ($6n \pm 1$) dominant harmonics are present in such system. These harmonics cause additional losses in the system, resonance, and failure of the capacitor bank. In a phase-controlled thyristor-based ELC, the phase angle of back-to-back-connected thyristors is delayed from 0. to 180. as the consumer load is changed from zero to full load [9]. Due to a delay in firing angle, it demands additional reactive power loading and injects harmonics in the system. In the controlled bridge rectifier type of ELC [10], a firing angle is changed from 0. to 180. For single phase and 0. to 120. for three phase to cover the full range of consumer load from 0% to 100%. In this scheme, six thyristors and their driving circuits are required, and hence, it is complicated, injects harmonics, and demands additional reactive power.

Some of ELCs have been proposed that are having quality of the active filter and employs pulse width modulation (PWM) voltage source converter along with the chopper and auxiliary load at dc link [10]–[13] to eliminate the harmonics and provide the functions of voltage and frequency regulation. However, such types of controllers make the system costly and complex with complicated control algorithm and simplicity requirement by the isolated system is lost. Therefore, in this paper, a simple ELC is proposed that regulates the voltage and frequency without any harmonic distortion at the generator terminals. The proposed controller consists of a 24-pulse rectifier, a chopper, and an auxiliary load. In place of six-pulse rectifier, a 24-pulse rectifier-based ELC has negligible harmonic distortion in the generated voltage and current. A comparative study based on simulation is presented and it is also verified experimentally for both types of ELCs.

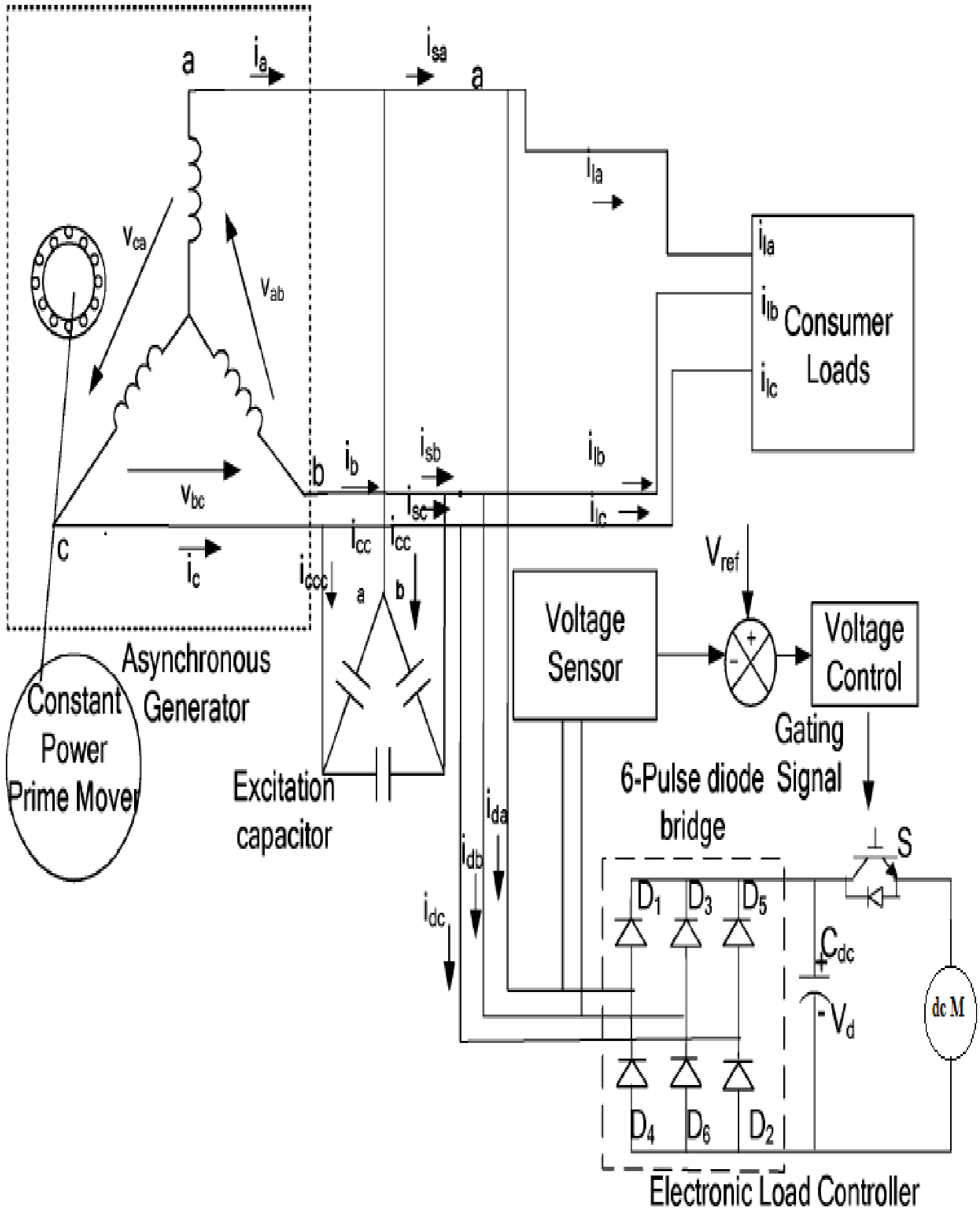


Fig.1. IAG system configuration and control strategy of a chopper switch in a six-pulse diode bridge ELC.

Conventional ELC (six-pulse diode rectifier along with the chopper). The diode bridge is used to convert ac terminal voltage of IAG to dc voltage. The output dc voltage has the ripples, which should be filtered, and therefore, a filtering capacitor is used to smoothen the dc voltage. An insulated gate bipolar junction transistor (IGBT) is used as a chopper switch providing the variable dc voltage across the auxiliary load. When the chopper is switched ON, the current flows through its auxiliary load and consume the difference power (difference of generated power and consumer load power) that results in a constant load on the IAG, and

hence, constant voltage and frequency at the varying consumer loads. The duty cycle of the chopper is varied by an analog-controller-based proportional–integral (PI) regulator. The sensed terminal voltage is compared with reference voltage and error signal is processed through PI controller. The output of PI controller is compared with fixed Frequency saw tooth wave to generate the varying duty cycle switching signal for the chopper switch. According to the principle of operation of the system, the suitable value of capacitors is connected to generate rated voltage at desired power [14]. The input power of the IAG is held constant at varying consumer loads. Thus, IAG feeds two loads (consumer load + ELC) in parallel such that the total power is constant.

$$P_{gen} = PELC + P_{load} \qquad (1)$$

Where P_{gen} is generated power by the IAG (which should be kept constant), P_{load} is consumed power by consumers, and PELC is the power absorbed by the ELC.

III. PROPOSED 24 PULSE SYSTEM DESCRIPTION

Fig. 2 shows the proposed reduced rating polygon connected autotransformer [15], [16] fed 24-pulse ac–dc-converter-based ELC for an isolated pico-hydropower generation applications. This configuration needs one zero-sequence blocking transformer (ZSBT) to ensure independent operation of the two rectifier bridges. It exhibits high impedance to zero-sequence currents, resulting in 120^0 conduction for each diode and also results in equal current sharing in the output. An inter phase reactor tapped suitably to achieve pulse doubling [17]–[18] has been connected at the output of the ZSBT. Two rectifiers output voltages Vd1 and Vd2 shown in Fig. 2 are identical but have a phase shift of 30. (Required for achieving 12-pulse operation), and these voltages contain ripple of six times the source frequency. The rectifier output voltage V_d is given by

$$V_d = 0.5\,(V_{d1} + V_{d2}) \qquad (2)$$

$$V_d = 0.5\,(V_{d1} + V_{d2}) \qquad (3)$$

Where Vm is an ac voltage ripple of 12 times the source frequency appearing across the tapped interphase reactor, as shown in Fig. 2.

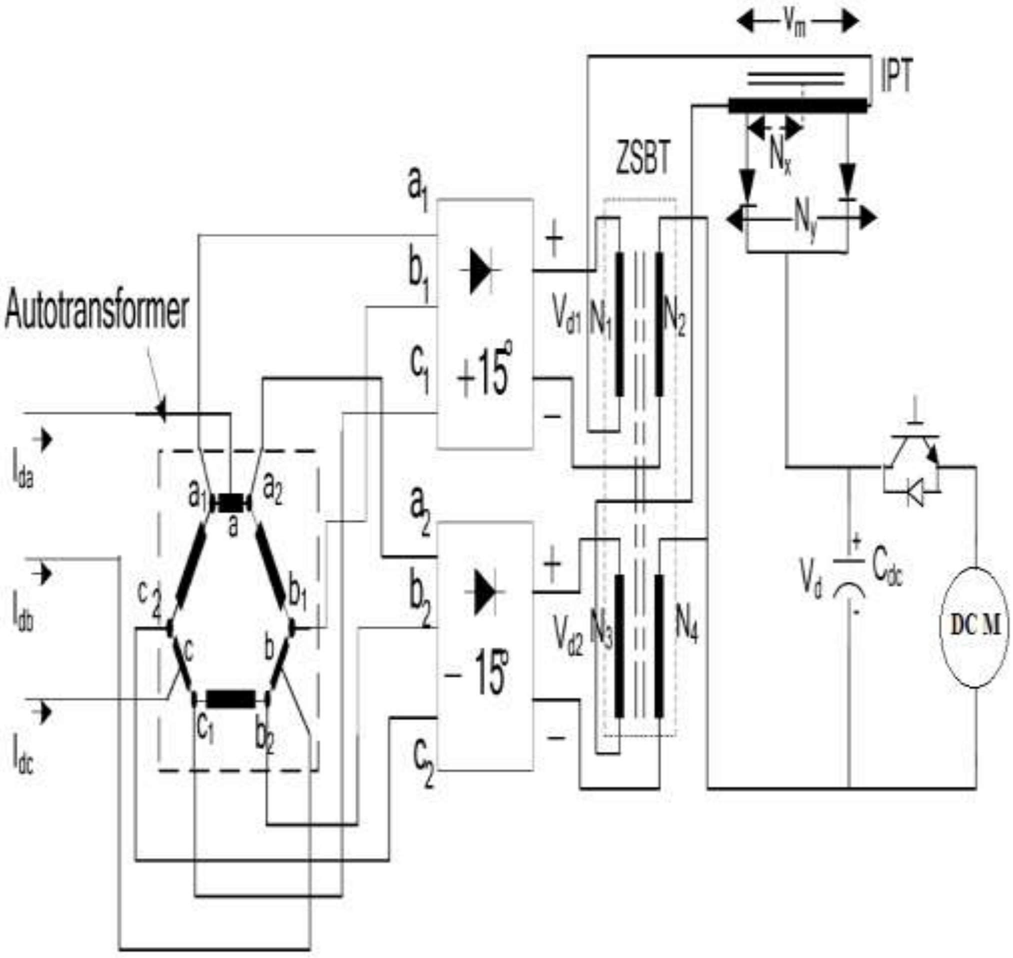


Fig.2 Proposed 24-pulse ELC for an IAG.

This pulse multiplication arrangement for diode bridge rectifiers has been used for desired pulse doubling for line current harmonic reduction. The ZSBT helps in achieving independent operation of the two rectifier bridges, thus eliminating the unwanted conducting sequence of the rectifier diodes. The ZSBT offers very high impedance for zero sequence current components. However, detailed design of the interphase reactor and ZSBT has been given in [18] and the same procedure is used in this paper. To achieve the 12-pulse rectification, the necessary requirement is the generation of two sets of line voltages of equal magnitude that are 30. out of phase with respect to each other (either ±15. or 0. and 30.). From the generator terminal voltages, two sets of three phase voltages (phase shifted through +150 and -150) are produced. The number of turns or voltage fraction across each winding of the autotransformer required for +15. and -15. phase shift is calculated by referring Fig.3 as follows:

$$V_{NS1} = V_{NS2} \quad (4)$$

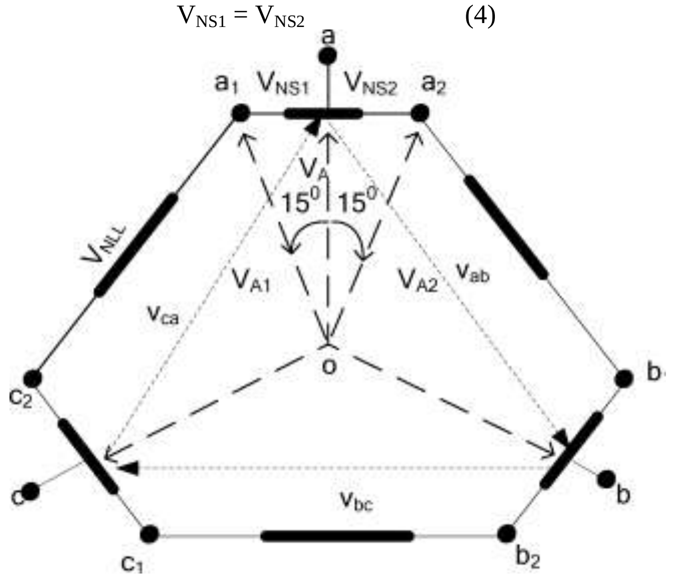


Fig. 3. Phasor and winding diagram of proposed 24-pulse autotransformer arrangement for 24-pulse ac–dc converter for proposed ELC.

Where Vca is the line voltage of 415V. The terms V_{NS1} and V_{NS2} are the voltage induced across the short winding and V_{NLL} is the induced voltage across the long winding of polygon connected autotransformer. Detailed hardware design of polygon connected autotransformer, ZSBT, and interphase transformer (IPT) are given in the Appendix along with the complete design of the proposed 24-pulse ELC.

V. MATLAB MODELLING AND SIMULATION RESULTS

A 7.5 kW, 415 V, 50 Hz asynchronous machine is used as an IAG and the ELC is modelled using available power electronics block set like diode bridge rectifier and a chopper with an auxiliary load and multi winding transformers are used to create the desired phase shift for 24-pulse converter operation. In the following sections the detailed comparison of two ELCs are explained.

Here, transient waveforms of the generator voltage (v_{abc}), generator current (i_{abc}), capacitor currents (i_{cabc}), consumer load current (i_{labc}), ELC current (i_{da},i_{db},i_{dc}), rms value of the generated voltage (v_{rms}), frequency (f), speed of the generator (w_g), variation in the load power (P_{load}), ELC power (P_{ELC}), and generated power (P_{gen})are given under the sudden application and removal of the consumer loads for both types of ELCs

A. Simulations of 6-pulse ELC

Fig. 5& 6 shows the different transient waveforms of IAG with conventional ELC using six-pulse diode bridge rectifier. In this the value of the capacitor is selected for generating the rated rms voltage (415 V) at rated load (7.5 kW). Initially, the consumer load is OFF and the ELC is consuming full 7.5 kW power to an auxiliary load. At 2 s, a consumer load of 5 kW is switched ON and it is observed that in order to maintain the constant power at the generator terminal, the current drawn by ELC is reduced, while by removing the consumer load at 2.3 s, it is again in-creased. Because of using six-pulse bridge-rectifier-based ELC, the distortion in the generator voltage and current is observed, and the magnitude and frequency of the generated voltage are controlled. Similar dynamics are performed in case of proposed 24-pulse ELC and explained in Fig. 6 and discussed in the following section in detail. Fig. 7 shows the harmonic spectra under zero load condition when conventional ELC draws maximum generated power; here, it is observed that due to nonlinear behaviour of this

ELC, it draws the current having total harmonic distortion (THD) of 37.13% which, in turn, distorts the voltage (THD of 8.3%) and current (THD of 11.33%) at the generator terminal.

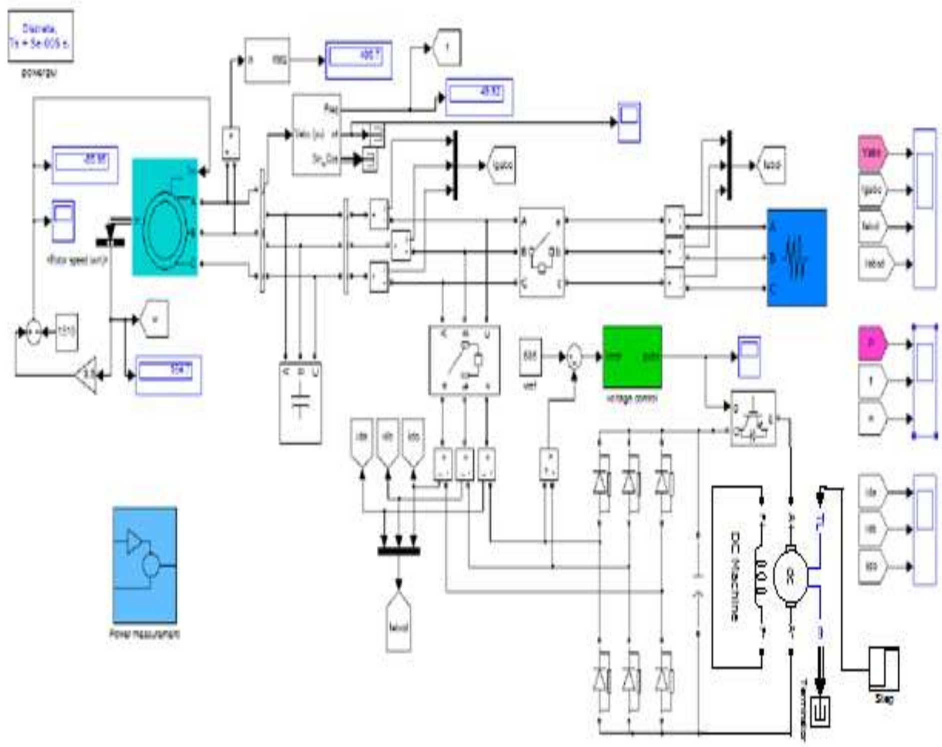


Fig. 4.Simulink model of IAG system configuration and control strategy of a chopper switch in a six pulse diode bridge ELC.

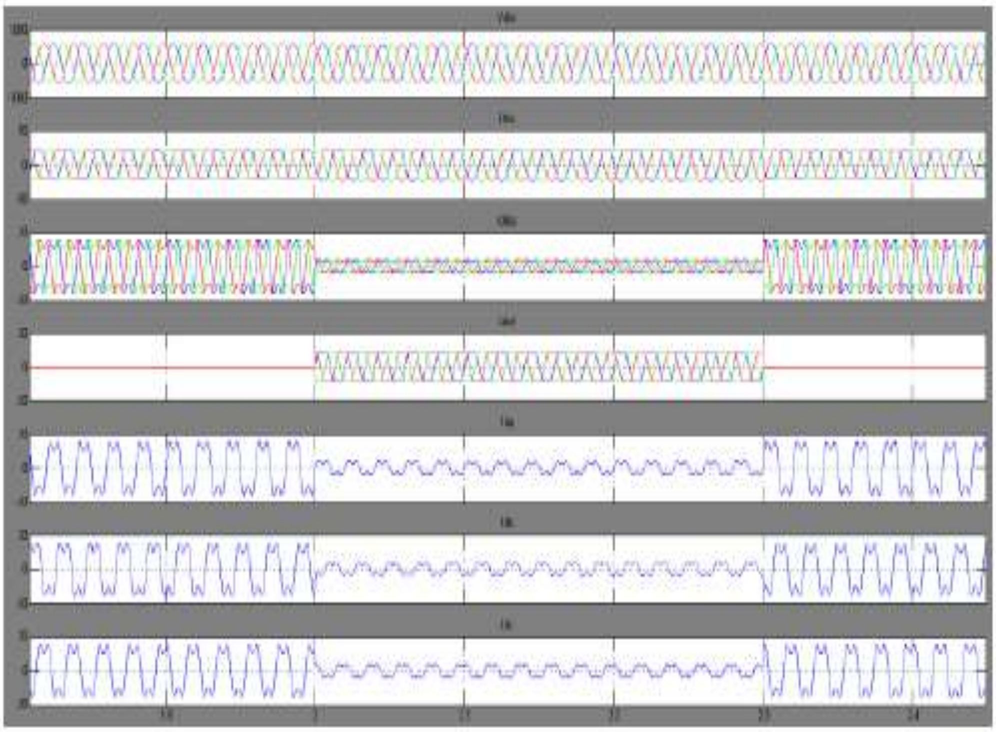


Fig.5 results of generator voltage, generator current, ELC current, load current and individual phase currents drawn by ELC respectively for 6 pulse ELC

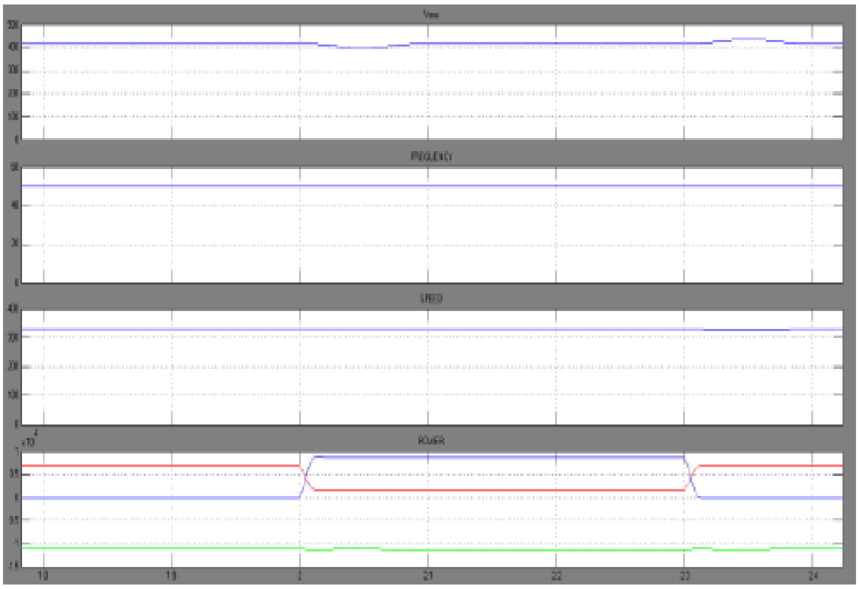
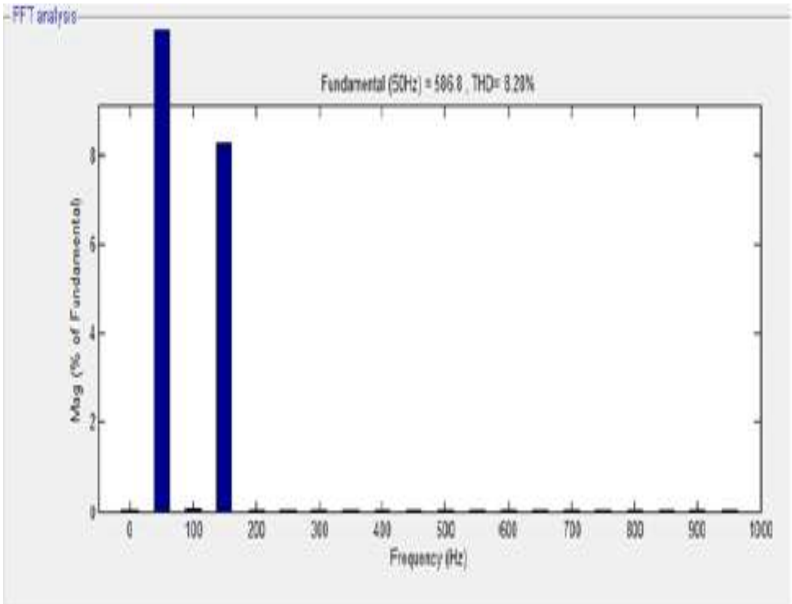
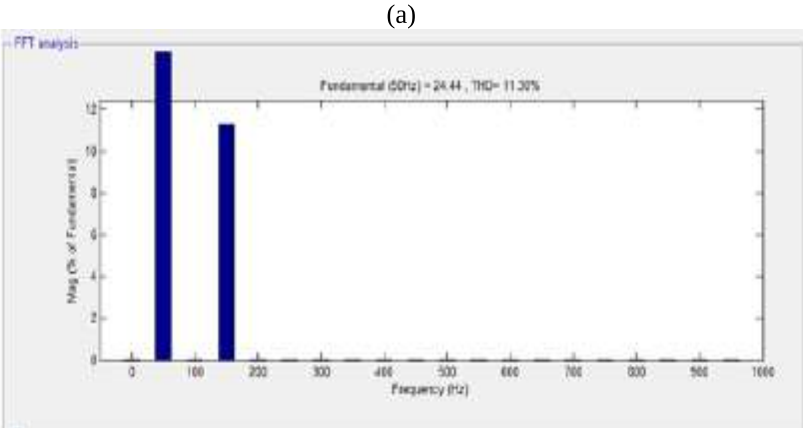


Fig. 6 results of generator voltage (rms), frequency, speed and power respectively for 6 pulse ELC



(a)



(b)

Fig 7. (a) Harmonic distortion in current drawn due to 6-pulse ELC
(b) Harmonic distortion in generated voltage due to 6-pulse ELC

B. Simulations of 24-pulse ELC

Fig.9 & 10 shows the transient waveforms of IAG using 24-pulse rectifier-based ELC. In similar manner of conventional ELC, the proposed ELC controls the constant power at generator terminal with variation of consumer loads. Here, it is observed that the voltage and frequency are maintained at constant value, and at the same time, the distortion in the generator voltage and current conventional ELC and the distortion in voltage and current of the generator is negligible compared to conventional ELC. Fig. 11 shows the harmonic spectra of the ELC current, generator voltage, and generator current, which shows that because of 24-pulse operation of an ELC, its performance is improved in comparison to conventional ELC and the distortion in voltage and current of the generator is observed almost negligible which is 0.42% and 0.48%, respectively.

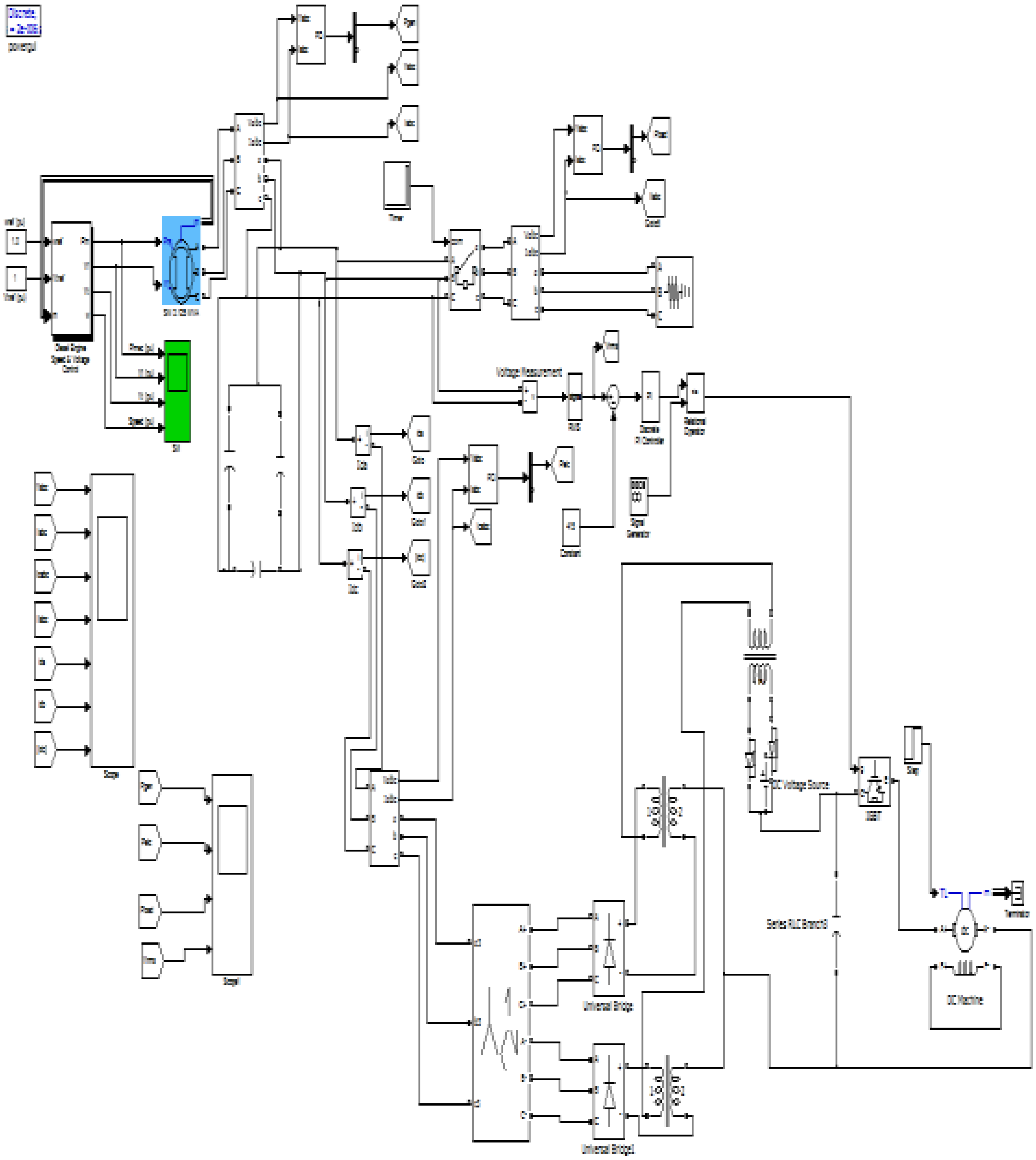


Fig. 8. Simulink model of IAG system configuration and control strategy of a chopper switch in a 24-pulse diode bridge ELC.

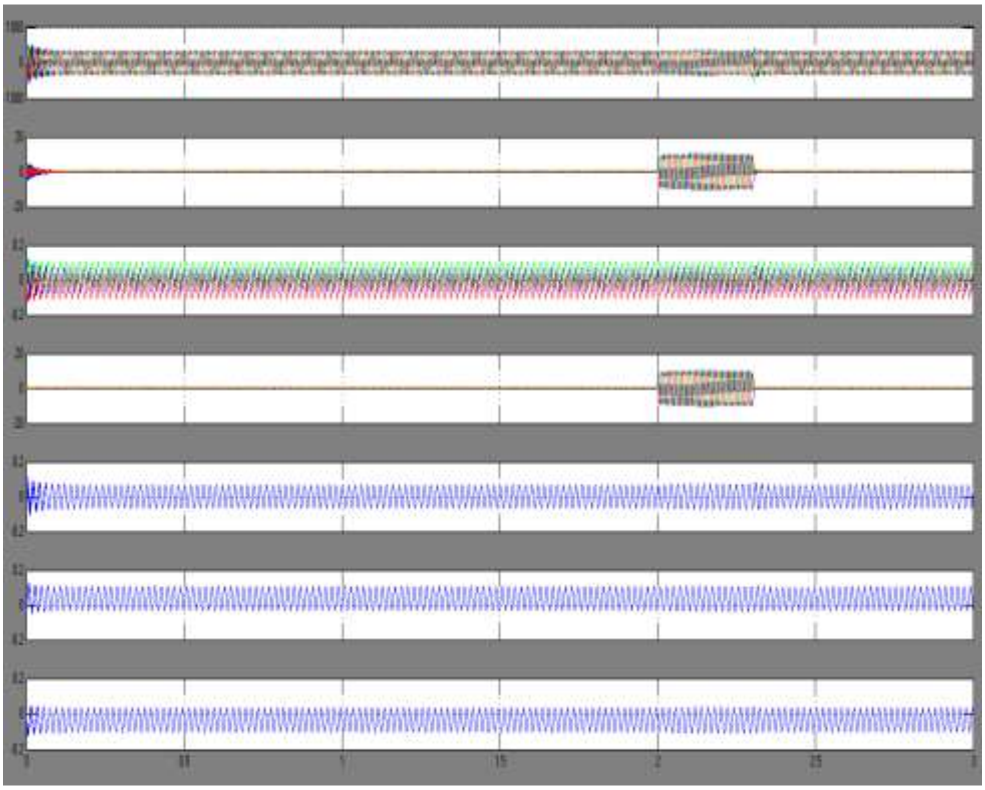


Fig. 9 results of generator voltage, generator current, ELC current, load current and individual phase currents drawn by ELC respectively for 24 pulse ELC.

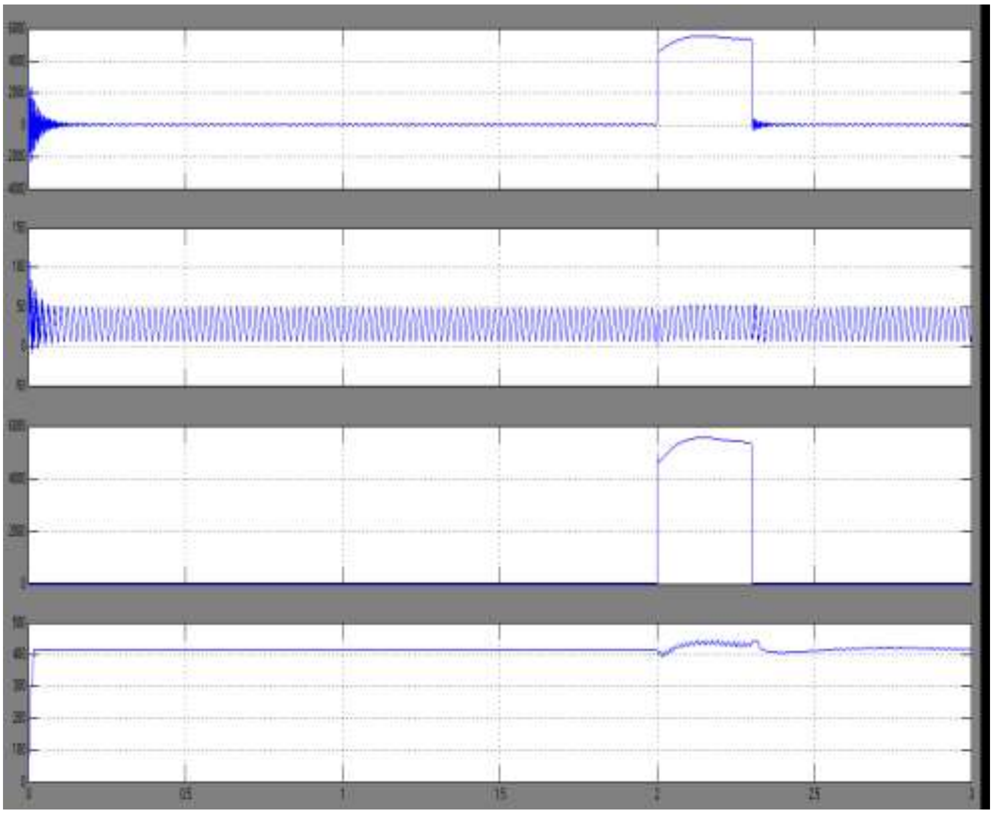
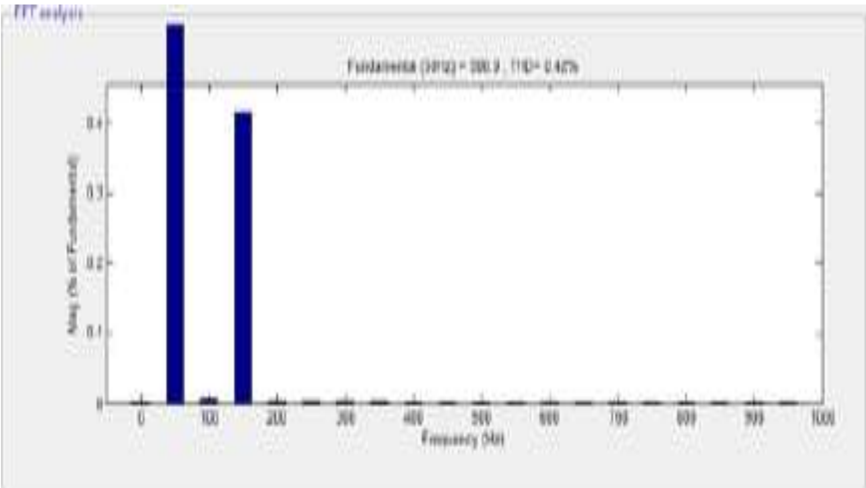
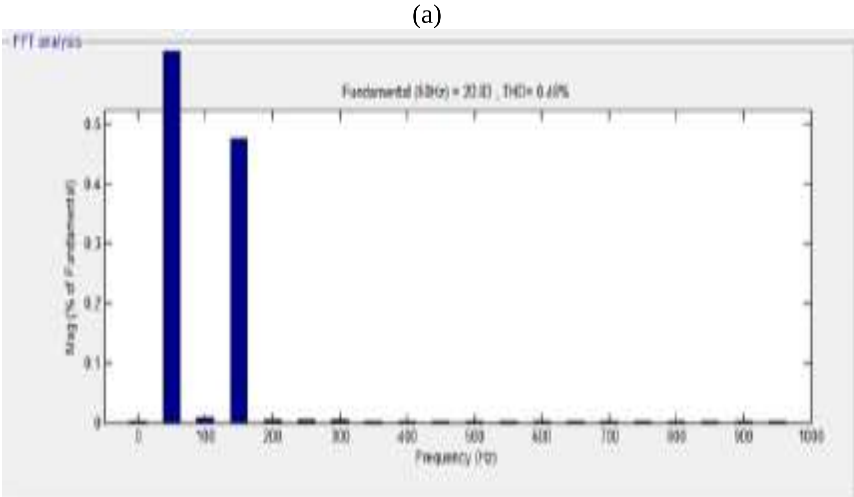


Fig. 10 results of generator voltage (rms), frequency, speed and power respectively for 24 pulse ELC.



(a)



(b)

Fig 11. (a) Harmonic distortion in current drawn due to 24-pulse ELC
(b) Harmonic distortion in generated voltage due to 24-pulse ELC

Table.1 Harmonic distortion in current drawn and generated voltage due to 6-pulse and 24-pulse respectively

Variable	**Total Harmonic Distortion**	
	6-pulse ELC	**24-pulse ELC**
current	8.28%	0.42%
generated voltage	11.30%	0.48%

V. CONCLUSION

Since the conventional ELC has high total Harmonic Distortion for the generated voltage and current under any load conditions and it is severe in case of zero consumer load condition due to the non linear behavior of ELC due to presence of six-pulse diode Rectifier. With the proposed ELC the total harmonic distortion for the generated voltage and current is low by maintaining constant power thus by improving the regulation of the IAG and thus improving the Power Quality in case of both balanced and unbalanced loads. The proposed ELC has been realized using 24-pulse converter and a chopper. A comparative study of both types of ELCs (6-pulse and 24-pulse configured ELC) has been demonstrated on the basis of simulation using standard software MATLAB/SIMULINK with simpower systems tool box and developing a hardware prototype in the laboratory environment.

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